



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 678

INTERFERENCE OF TAIL SURFACES AND WING AND FUSELAGE FROM TESTS OF 17 COMBINATIONS IN THE N. A. C. A. VARIABLE-DENSITY TUNNEL

By ALBERT SHERMAN



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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

		Metric	200	English				
	Symbol	Unit	Abbrevia- tion	Unit	Abbrevia- tion			
Length Time Force		metersecondweight of 1 kilogram	m s kg	foot (or mile) second (or hour) weight of 1 pound	ft. (or mi.) sec. (or hr.) lb.			
PowerSpeed	P V	horsepower (metric) {kilometers per hour meters per second	k.p.h, m.p.s.	horsepower miles per hour feet per second	hp. m.p.h. f.p.s.			

2. GENERAL SYMBOLS

W,	Weight=mg	v, Kinematic viscosity
g,	Standard acceleration of gravity=9.80665	ρ, Density (mass per unit volume)
31	m/s ² or 32.1740 ft./sec. ²	Standard density of dry air, 0.12497 kg-m ⁻⁴ -s ² at
	W	15° C. and 760 mm; or 0.002378 lbft4 sec.2
m,	$Mass = \frac{n}{q}$	Specific weight of "standard" air, 1.2255 kg/m3 or
I,	Moment of inertia $= mk^2$. (Indicate axis of	0.07651 lb./cu. ft.
	radius of gyration k by proper subscript.)	
μ,	Coefficient of viscosity	

	3. AERODYNAI	MIC SY	MBOLS
$S,$ $S_w,$ $G,$	Area Area of wing Gap	i_w , i_t ,	Angle of setting of wings (relative to thrust line) Angle of stabilizer setting (relative to thrust line)
$\begin{array}{c} b, \\ c, \\ b^2 \end{array}$	Span Chord	Q , Ω ,	Resultant moment Resultant angular velocity
$\frac{b^2}{\overline{S}}$, V ,	Aspect ratio True air speed	$\rho \frac{Vl}{\mu}$	Reynolds Number, where <i>l</i> is a linear dimension (e.g., for a model airfoil 3 in. chord, 100
q,	Dynamic pressure $=\frac{1}{2}\rho V^2$		responding number is 234,000; or for a model
L,	Lift, absolute coefficient $C_L = \frac{L}{qS}$	C_p ,	of 10 cm chord, 40 m.p.s., the corresponding number is 274,000) Center-of-pressure coefficient (ratio of distance
D_0 , D_0 ,	Drag, absolute coefficient $C_D = \frac{D}{qS}$ Profile drag, absolute coefficient $C_{D_0} = \frac{D_0}{qS}$	α ,	of c.p. from leading edge to chord length) Angle of attack
D_i	Induced drag, absolute coefficient $C_{D_4} = \frac{D_4}{qS}$	ε, αο,	Angle of downwash Angle of attack, infinite aspect ratio
D_p ,	Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$	α_i , α_a ,	Angle of attack, induced Angle of attack, absolute (measured from zero-
<i>C</i> ,	Cross-wind force, absolute coefficient $C_c = \frac{C}{qS}$	γ,	lift position) Flight-path angle
R,	Resultant force		

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By Albert Sherman

SUMMARY

An investigation of the interference associated with tail surfaces added to wing-fuselage combinations was included in the interference program in progress in the N. A. C. A. variable-density tunnel. The results indicate that, in aerodynamically clean combinations, the increment of the high-speed drag can be estimated from section characteristics within useful limits of accuracy. The interference appears mainly as effects on the downwash angle and as losses in the tail effectiveness and varies with the geometry of the combination. An interference burble, which markedly increases the glide-path angle and the stability in pitch before the actual stall, may be considered a means of obtaining satisfactory stalling characteristics for a complete combination.

INTRODUCTION

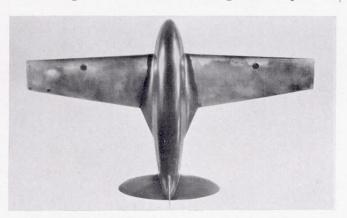
The investigation that the Committee has been conducting in the variable-density wind tunnel of the aerodynamic interference between the wing and the fuselage (references 1 to 6) has been extended to include the interference associated with the tail surfaces. Comparable data at large scale are thus made available on the aerodynamic interference between the component parts of related complete combinations.

Representative wing-fuselage combinations were tested, to which had been added two different types of tail surface: conventionally arranged tail surfaces of semi-elliptical plan form and rectangular horizontal tail surfaces with elliptical end plates. The tests were restricted to the conditions of zero elevator deflection and zero yaw, and the effects of the interference on the drag, the downwash angle, and the tail effectiveness were mainly considered. Effects of the following variables were studied: wing position, angle of wing setting, form of tail surface, and form of wing-root juncture. A comparison of calculated and experimental data on the downwash angle at the tail is also included.

MODELS AND TESTS

The wing employed is the tapered wing described in reference 1; it is a duralumin model having an area of 150 square inches, aspect ratio 6, taper ratio 2, and the N. A. C. A. 0018 section at the root and the N. A.

C. A. 0009 section at the tip. It was combined with the fuselage in the standard longitudinal position,





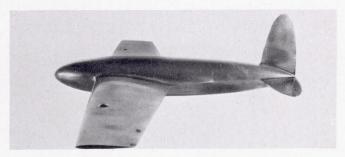




FIGURE 1.—Combination 314 showing elliptical tail surfaces.

d/c=0. The fuselage is the round fuselage described in reference 1; it is an airship form having a length of

20.156 inches and a fineness ratio of 5.86. The tapered fillets (reference 1) were carefully constructed of plaster

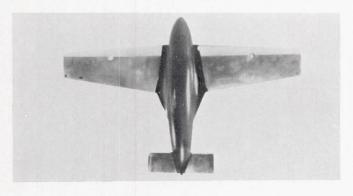
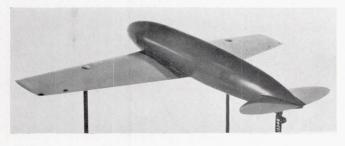








FIGURE 2.—Combination 316 showing rectangular tail surfaces with end plates.



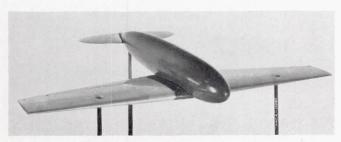
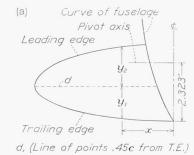
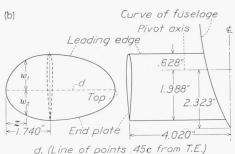


FIGURE 3.—Combination 329 showing unfilleted juncture.

of paris and were given the polished lacquer finish now standard for the wing-fuselage-interference investigation (reference 5). Figures 1, 2, and 3 are photographs of interesting combinations and show the proportions of the tail surfaces and their location on the fuselage axis.

The details of the tail surfaces are given in figure 4. For the elliptical tail surfaces, the vertical surface is identical with each of the horizontal surfaces. The tail with end plates has approximately the same total wetted area as the elliptical horizontal and vertical tail surfaces, but its calculated total-lift-curve slope was predicted from the theory of reference 7 to be 84





	(in.)	$(\operatorname{in.})^{y_1}$	(in.)
(a) Elliptical tail surface: Fin area: 11.46 sq. in.; 0.076 of wing area. Area horizontal surfaces (including 4.08 sq. n. in fuselage): 27.00 sq. in.; 0.18 of wing area.	0 1. 0 2. 0 3. 0 4. 0 5. 0 5. 51	1. 403 1. 381 1. 308 1. 177 . 965 . 588	1. 598 1. 439 1. 179 . 718
	z	w_1	w_2
(b) Tail surface with end plate: Fin (end plates) area: 17.88 sq.in.; 0.119 of wing area. Area horizontal surfaces (including 3.70 sq.in. in fuselage): 21.02 sq.in.; 0.14 of wing area.	0 . 240 1. 240 2. 240 3. 240 4. 240 4. 352	0 . 728 1. 378 1. 412 1. 178 . 416	0 . 596 1. 126 1. 154 . 964 . 340

FIGURE 4.—Details of the tail surfaces—N. A. C. A. 0009 sections.

percent as large. Only very small fillets were used at the tail surfaces (see figs. 1 and 2) because filleting was believed unnecessary for the junctures employed. The test results do not indicate that larger fillets would be an improvement. Table V contains the descriptions of the combinations (314 to 330) that make up this investigation.

The combinations were tested in the variable-density wind tunnel (reference 8) at a test Reynolds Number of approximately 3,100,000, corresponding to an effective Reynolds Number of 8,200,000 for $C_{L_{max}}$. (See reference 1.) In addition, values of the maximum lift coefficient were obtained at a reduced speed correspond-

ing to an effective Reynolds Number of 3,700,000. The testing procedure and the test precision were about the same as for an airfoil (reference 8). The three-component balance of the variable-density wind tunnel restricted the study of the vertical tail surfaces to the zero-yaw condition.

based on the projected wing area of 150 square inches and on the mean chord of 5 inches. The methods for analysis of the test data and for presentation of the test results are explained in reference 1.

Tables I and II, taken from reference 1, contain the aerodynamic characteristics of the wing and of the

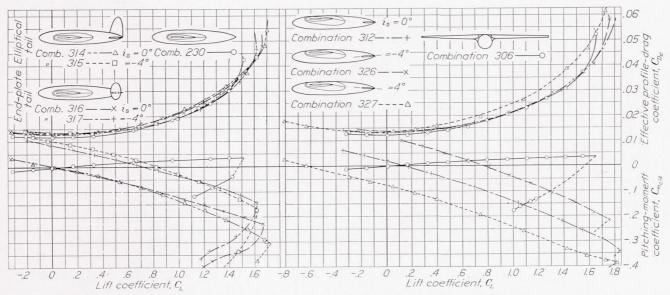


FIGURE 5.—Characteristics of midwing combinations with various tail surfaces. Tapered N. A. C. A. 0018–09 airfoil and round fuselage; k/c=0; $i_w=0^\circ$.

FIGURE 6.—Effects of tail setting on the characteristics of high-wing combinations. Tapered N. A. C. A. 0018-09 airfoil and round fuselage; k/c=0.22; $i_w=0^{\circ}$.

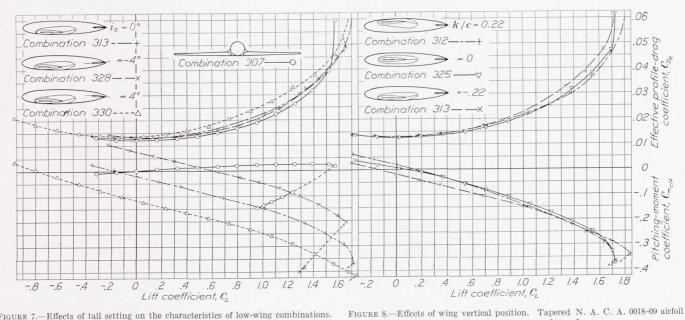


FIGURE 7.—Effects of tail setting on the characteristics of low-wing combinations. Tapered N. A. C. A. 0018–09 airfoil and round fuselage; $k/c=-0.22;\ i_w=0^\circ.$

round fuselage; $i_v = 0^\circ$: and round fuselage; $i_w = 0^\circ$: $i_s = 0^\circ$

RESULTS

The test results are given in tables I, II, III, IIIa, and V supplemented by figures 5 to 10. Data from previous reports are included for comparison. Additional derived data on tail interference and downwash angle at the tail are presented in the text of the discussion and in figure 11. The aerodynamic characteristics are given as standard nondimensional coefficients

fuselage, respectively. Table III, continued from reference 6, presents the sums of the fuselage characteristics and interferences $(\Delta C_L, \Delta C_{D_e}, \Delta C_{m_{c/4}})$ for the different combinations at various angles of attack. Table IIIa, continued from reference 6, presents the sums of the characteristics and interferences of the tail surfaces. The characteristics of the combinations themselves can be determined by adding the corresponding items in tables I, III, and IIIa.

 n_0

Table IV of reference 1, which presents the data for disconnected combinations (combinations for which the forces on the components are measured separately), is omitted herein as it is in references 2 to 6 because no further tests of this nature were performed. The table numbers are maintained as in reference 1, however, to preserve the continuity of the published test results of the interference investigation.

Table V, continued from reference 6, contains the principal geometric and aerodynamic characteristics of the combinations. The values d/c and k/c represent the longitudinal and the vertical displacements, respectively, of the wing quarter-chord axis measured (in mean chord lengths) positive ahead of and above the quarter-length point of the fuselage axis. The value

tions with tail surfaces, however, the lift at an arbitrary angle of trim, i. e., where $C_{m_{e/4}}=0$, is given instead.

aerodynamic-center position, indicating approximately the location of the aerodynamic center ahead of the wing quarter-chord axis as a fraction of the mean wing chord. Numerically, n_0 equals $dC_{m_c/4}/dC_L$ at zero lift. For the combinations with tail surfaces, however, n_0 is given instead for the arbitrary trim condition, i. e., at $C_{m_{c/4}}=0$.

 C_{m_0} , pitching moment at zero lift. $C_{L_{tb}}$, lift coefficient at the interference burble, i. e., the value of the lift coefficient beyond which

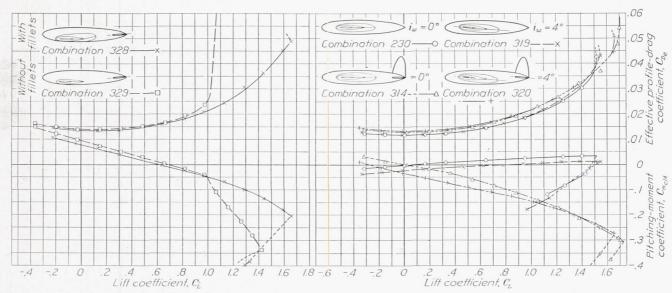


FIGURE 9.—Effects of fillets on the characteristics of low-wing combinations. Tapered N. A. C. A. 0018–09 airfoil and round fuselage; k/c = -0.22; $i_w = 0^\circ$; $i_s = -4^\circ$.

FIGURE 10.—Effects of wing setting on the characteristics of midwing combinations. Tapered N. A. C. A. 0018-09 airfoil and round fuselage; k/c=0; $i_s=0^\circ$.

 i_w is the angle of wing setting with respect to the fuselage axis and i_s is the setting of the tail surfaces relative to the wing.

The last nine columns of table V present the following important aerodynamic characteristics:

a, lift-curve slope (in degree measure) as determined in the range of low lift coefficients for an effective aspect ratio of 6.86. This value of the aspect ratio differs from the actual value for the models because the lift results are not otherwise corrected for tunnel-wall interference.

e, Oswald's airplane, or span, efficiency factor. (See reference 1.)

 $C_{D_{e_{min}}}$, minimum effective profile-drag coefficient $\left(C_D - \frac{C_L^2}{\pi A}\right)_{min}$ corresponding to the test Reynolds Number.

 $C_{\mathcal{L}_{opt}}$, optimum lift coefficient, i. e., the lift coefficient corresponding to $C_{\mathcal{L}_{\varrho_{min}}}$. For the combina-

the air flow has a tendency to break away as indicated by an abnormal drag increase.

 $C_{L_{max}}$, maximum lift coefficient given for two different values of the effective Reynolds Number. (See reference 1.) The turbulence factor employed in this report to obtain the effective R from the test R is 2.64.

As in reference 2, the values of the effective Reynolds Number differ somewhat from those given in reference 1 because of a later determination of the turbulence factor for the tunnel. The values of the effective Reynolds Number given in reference 1 can be corrected by multiplying by 1.1.

The data thus presented for the combinations with tail surfaces are directly applicable to design purposes only at the attitude for trim, that is, when the pitching moment about the center of gravity is zero. At other attitudes, the conditions of the tests cannot be reproduced in steady flight. The most important interference effects for tail surfaces, however, should be satisfactorily indicated over the range of lift coefficients by these results.

DISCUSSION

LIFT

The horizontal tail surfaces at constant setting add to the lifting area of a combination and should therefore increase the lift-curve slope. For the combinations tested, the gain in lift-curve slope amounted, within the limits of the test accuracy, practically to the value that would be calculated from the lift expected of the tail operating alone as a wing, the downwash and the wake interferences being neglected. The observed increases in the maximum lift (table V) naturally cannot be considered real as they were obtained with undeflected elevators and highly unbalanced pitching moments. The effect on the maximum lift of the interference of tail surfaces with elevators deflected is outside the scope of this investigation.

DRAG

The experimental increments of the minimum drag coefficients of the combinations due to the semielliptical tail surfaces at 0° setting (0.00035 to 0.00055 per surface) agree within the test accuracy with a value estimated from section characteristics and the wetted area (0.00045 per surface). This agreement shows that no large resultant interference effect of the tail surfaces could have been present. The horizontal tail surfaces set $\pm 4^{\circ}$ show larger contributions to the minimum drag than those set 0°, but the differences are generally too small to be important. (See table V.)

Over the range of low to moderate lift coefficients, the variation in the drag increment also was unimportant for two of the tail settings investigated (0° and -4°) and, moreover, was often favorable (figs. 5, 6, and 7). For a tail setting of 4°, however, this variation was appreciable and adverse.

From the foregoing considerations it can be concluded that, with regard to the high-speed or cruising drag, cleanly constructed tail surfaces within the normal range of tail settings may be satisfactorily allowed for in design by simple calculations based on section characteristics and the wetted area, neglecting interferences. Incidentally, the data indicate how low a drag should be expected from cleaning up the conventional airplane design. The value of 0.0135 $(R=3\times10^6)$ for the effective profile-drag coefficient for combinations 314 and 315 (fig. 5) at a C_L of about 0.3 represents the drag obtainable for a small airplane. In view of the turbulence present in the air stream of the variable-density wind tunnel and the unevaluated part of the supportstrut interference, this value is believed to be conservative. Extrapolation of the drag values given in this report to higher Reynolds Numbers can be made by the methods described in reference 9.

PITCHING MOMENT

The horizontal tail surfaces are employed to provide stability in pitch. They form what is essentially an airfoil operating under the influence of an interfering body, the wing-fuselage combination. The most important interferences at the tail may be separated into two effects: that on the flow direction, or the downwash; and that on the flow velocity, or the wake.

Downwash and wake.—When the wing-fuselage combination is lifting, the downflow components induced by the vortex pattern in the air stream reduce the effective angle of attack at the tail by an amount referred to as the "downwash angle" ϵ .

The evaluation of ϵ is necessary in stability calculations. A method exists for the prediction of the

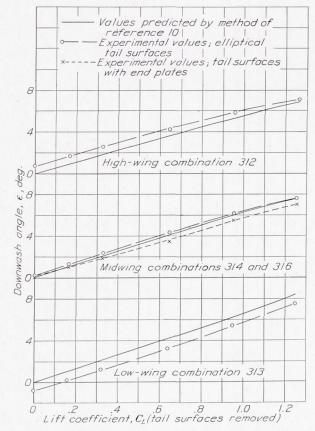


Figure 11.—Comparison of experimental and predicted values of the downwash angle at the tail. $A\!=\!6.86$.

downwash angle at the tail associated with any type of wing (reference 10), but the amount that ϵ is modified by the interference in a wing-fuselage combination remains to be found. Figure 11 gives a comparison of values of the average downwash angle over the tail span as calculated by the method of reference 10 and as derived from the experimental results for the elliptical tail surfaces on the high-wing, the midwing, and the low-wing combinations. Experimental values of ϵ for the tail with end plates on the midwing combination are included. The method employed to obtain the experimental values was as follows: At each specified angle of attack, the rate of change of pitching moment with the angle of attack of the tail was determined from the pitching moments for tail settings of

 -4° , 0° , and 4° . Next, the change produced in the pitching moment by adding the tail surfaces was divided by the rate just derived to give the effective angle of attack of the tail. The experimental value of the downwash angle ϵ , then, was the difference between the geometric angle of attack of the tail and its effective angle of attack. This procedure avoided the complications of the wake interference and the tail effectiveness.

It can be seen from figure 11 that, for the elliptical tail on the symmetrical midwing combination, the agreement between the predicted and the experimental downwash angles is good over the range of low to moderate lift coefficients. Apparently, the interference of the fuselage and the junctures was negligible. For the high-wing and the low-wing combinations, the agreement is poor. The discrepancy, however, is practically constant, therefore of little importance in stability calculations, and is of opposite sign for the highwing and the low-wing combinations. Apparently, at zero lift the tail surfaces have already an initial effective angle of attack of approximately 0.8° for the lowwing and -0.8° for the high-wing combinations. pitching-moment curves of figs. 6, 7, and 8.) The geometrical asymmetry, then, produces an initial deviation in the flow at the tail impossible to derive from a theory that considers only the wing. A comparison of figures 7 and 9 shows that most of this interference is chargeable to the fillets. The same effect can be produced, however, by other sources of asymmetry, such as wing setting. (Cf. curves of pitching moment in fig. 10, and also C_{m_0} for combinations 314 and 322 in table V.)

Figure 5 shows that, for zero tail setting and at low to moderate lift coefficients, the tail surfaces with end plates produce as large a change in the pitching moment as the elliptical tail surfaces, indicating that they should have as high a slope of the total-lift curve. The slope for the end-plate tail, however, has been calculated to be only 84 percent of that for the elliptical tail. This calculation appears corroborated, moreover, by the change in the pitching moment at zero lift developed by the end-plate tail, corresponding to a change from 0° to -4° in tail setting, which was also about 84 percent of the change produced by the elliptical tail (fig. 5). The apparent inconsistency may be explained by the experimental, and unexpected, circumstance that the average downwash angle affecting the endplate tail was slightly less than that affecting the elliptical tail and balanced its lower lift-curve slope. (See fig. 11. Refer also to pitching-moment curves in fig. 5.) No explanation for this difference in downwash is offered. Further investigation of tail surfaces of different geometric characteristics may provide a better understanding of the nature of such interference phenomena.

Stability at the stall.—The problem of obtaining satisfactory stalling characteristics is commanding attention in connection with the refined present-day monoplanes. An essential feature of a satisfactory stall is that it give ample warning, associated preferably with rapidly increasing stability in pitch. Figure 9 presents the aerodynamic characteristics for a low-wing unfilleted combination of moderate aspect ratio (see fig. 3) that employs a common method of achieving such a stall, an interference burble (see reference 1); the burble occurred at a lift coefficient of about 1.0, which is above the climbing range, and resulted in a loss of downwash at the tail. As the angle of attack was increased, the lift continued to increase slowly to the maximum but the diving moment and the drag rose precipitously, insuring a steeper glide path, an appreciable increase in stability in pitch, and thus a warning of the approaching It is understood from flight results that some tail buffeting may occur simultaneously; this buffeting is an unmistakable warning that cannot be overlooked. The interference burble can be delayed to a higher lift coefficient, if so desired, and the cost in maximum lift and minimum drag can be reduced by small fillets. The use of the interference burble is therefore not necessarily a makeshift solution in the design of airplanes for acceptable stalling characteristics.

Tail factor.—The tail factor, η_t , may be defined as the ratio of experimental to calculated changes in the pitching moment due to the horizontal tail surfaces. The calculated changes may be derived from the geometric and the aerodynamic characteristics of the tail surfaces with due allowance for the downwash angle and the flow velocity at the tail as affected by the wake. Ordinarily, the factor is derived from the experimental and the calculated changes in the pitching moment of the combination produced by different settings of the tail surfaces for a given angle of attack of the wing. This procedure avoids the complications involved with the downwash angle at the tail. Such a derivation results, however, in a factor corresponding to a varying angle of tail setting rather than one for a varying angle of attack of the combination as a whole. The interferences associated with various tail-surface settings might possibly differ, and hence the factor as ordinarily obtained would not strictly apply to stability calculations for which the tail changes angle together with the combination. As will be shown later, however, the variation in tail factor over a moderate range of angles of tail setting is generally unimportant for combinations such as reported herein.

COMPARISON OF TAIL FACTOR FOR DIFFERENT WING-FUSELAGE COMBINATIONS

Combi- nation	k/c	i_w (deg.)	i_s (deg.)	(av	il facto veraged =0° to =	for	$\Delta \left(\frac{d C_{m_{ \mathrm{c}}/4}}{d C_{ L}} \right) $				
							$\alpha = 0^{\circ}$	α=4°	$\alpha = 12^{\circ}$		
			Е	lliptica	al tail s	urfaces					
314	0	0	0	10.00	0.01	0. 91	∫-0.128	-0.157	-0. 202		
	0	0	-4	30.90	0.91		(127	146	196		
327	. 22	0	4	. 79	. 82		164	−. 198	221		
3121	. 22	0	0	\\ 0.90\\ .79\\ \ .81\\ \ .81\\ \ \ .81\\ \ \ \ .81\\ \ \ \ .81\\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	.82	. 90	162	−. 179	—. 219		
326	29	0	-4	. 81	.82		167	180	-213		
	22	0	4	.81	. 81	. 90	168	146	—. 191		
313 1	22	0	0	{ .81 .79	.81	. 90	160	151	158		
328	22	0	-4	.79	.79	.84	159	 153	151		
			Tail	surface	s with	end pla	tes				
	0	0 0	0 -4	0. 92	0.89	0.89	$\begin{cases} -0.132 \\ -143 \end{cases}$	-0.160 150	-0.164 157		

¹ From reference 6.

If the tail factor is derived as described, it will differ from unity by an amount proportional to the *unevaluated* interference. Reference 10 contains methods of obtaining the interference behind the wing. The interference with a fuselage present remains to be investigated. The preceding table presents a comparison of tail factors for various combinations with allowance made for the interference of the wing alone n accordance with the methods of reference 10.

Notice that η_t is practically constant for the symmetrical midwing combinations over the range of angles of attack investigated. For the high-wing and the lowwing combinations, the factor shows greater amounts of unevaluated interference at low angles of attack than for the midwing combination. Most of the difference is believed to result from the asymmetry introduced by the fillets. (Notice in fig. 9 the reduction of slope in the pitching-moment curve associated with the fillets.) It appears, therefore, that a knowledge of the interference behind a wing alone is insufficient for calculating the effectiveness of tail surfaces in combinations. Until further research more fully evaluates the interference at the tail of combinations, estimates based upon test results, such as in this report, must be relied upon in stability calculations.

The values of η_t given are obviously averages for the two tail settings employed in each derivation. For any combination chosen, at a specified angle of attack, the downwash angle and the wake interference may be assumed unchanged for various tail settings. Under such conditions, a variation in the change produced in the slope of the pitching-moment curve by adding tail surfaces $\Delta\left(\frac{dC_{m_{c/4}}}{dC_L}\right)$ is a direct indication of a variation in the tail factor. From the columns of $\Delta\left(\frac{dC_{m_{c/4}}}{dC_L}\right)$ in the preceding table, it can be concluded that the tail setting did not, in general, greatly affect the tail factor

at the lower lift coefficients within the range investigated and within the accuracy of the data. It appears, therefore, that a factor derived from a small range of tail settings is reasonably applicable to horizontal tail surfaces that change angle together with the combination as a whole. Check calculations with the data using factors so derived corroborated this conclusion by correctly predicting the curves of pitching moment produced by the tail surfaces.

The factors of the tail with end plates in the symmetrical midwing combination are practically the same as those of the elliptical tail. (Cf. also values of $\Delta \left(\frac{dC_{m_c/4}}{dC_L}\right)$.) This agreement indicates that the unevaluated interference is not intimately connected with the geometry of the tail surfaces themselves.

CONCLUSIONS

The results of the present tests show that:

- 1. The increment of the drag in the high-speed range caused by adding tail surfaces in the normal range of tail settings to clean combinations can be estimated within useful limits of accuracy from section characteristics and the wetted area, the interference being neglected.
- 2. The interference of the fuselage in symmetrical midwing combinations on the downwash angle behind the wing is small.
- 3. The effect of asymmetry in the combination is to introduce a corresponding initial deviation in the air stream at the tail.
- 4. The effective downwash angle at the tail may vary somewhat with the geometry of the tail surfaces under consideration.
- 5. An interference burble for a combination of wing, fuselage, and tail surfaces may be considered a satisfactory means of producing acceptable stalling characteristics.
- 6. For combinations such as were investigated, large fillets at the tail-surface junctures are unnecessary.
- 7. Knowledge of the interference behind the wing alone is not sufficient for evaluating the effectiveness of tail surfaces added to wing-fuselage combinations.

Langley Memorial Aeronautical Laboratory, National Advisory Committee for Aeronautics, Langley Field, Va., November 5, 1938.

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TABLE I

AIRFOIL CHARACTERISTICS

Airfoil	C_L C_{D_e} C_m			C_L	$C_{D_{e}}$	$C_{m_{c/4}}$	C_L	$C_{D_{\mathfrak{G}}}$	$C_{m_{c/4}}$	
		$\alpha = 0^{\circ}$			α=4°		α=12°			
Tapered N. A. C. A. 0018-09	0.000	0.0093	0.000	0.305	0.0099	0.006	0.910	0.0146	0.013	

TABLE II

FUSELAGE CHARACTERISTICS

Fuse-	En- gine	C_L	C_D	C_{m_F} 1	C_L	C_D	C_{m_F} ¹	C_L	C_D	C_{m_F} 1	C_L	C_D	C_{m_F} 1	C_L	C_D	C_{m_F} 1	
lage	gine	e α=0°				α=4°			α=8°			α=12°			α=16°		
Rcund_	None	0.000	0.0041	0.000	0.001	0.0042	0.016	0.005	0.0049	0.028	0.011	0.0062	0.035	0.019	0.0085	0.038	

¹ Pitching-moment coefficient about the quarter-chord point of the fuselage.

TABLE III

LIFT AND INTERFERENCE, DRAG AND INTERFERENCE, AND PITCHING MOMENT AND INTERFERENCE OF FUSELAGE IN WING-FUSELAGE COMBINATIONS

Com- bina-	ΔC_L	ΔC_{D_e}	$\Delta C_{m_c/4}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_c/4}$	ΔC_L	$\Delta C_{D_{\mathfrak{G}}}$	$\Delta C_{m_c/4}$	
tion		$\alpha = 0^{\circ}$			α=4°		α=12°			
230 319	0.003 016	0.0024 .0024	-0.003 023	0.023 001	0.0024 .0025	0.003 019	0.042	0.0040	0.012	
321 306	020 . 008	.0028	022 001	001 004 . 019	.0023	019 016 . 003	.030	.0040 .0035 .0059	009 002 . 012	
307 308	008 017	.0029	.001	013 011	.0028	.005	037 004	.0044	.011	
309 187	.017	.0025	009 008	.036	.0027	004 001	. 046	. 0047	.006	

TABLE IIIa

LIFT AND INTERFERENCE, DRAG AND INTERFERENCE, AND PITCHING MOMENT AND INTERFERENCE OF TAIL SURFACES IN COMBINATIONS

Com- bina-	ΔC_L	$\Delta C_{D_{e}}$	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/4}}$	ΔC_L	ΔC_{D_e}	$\Delta C_{m_{c/s}}$		
tion		α=0°			α=4°		α=12°				
310	0.005	0.0011	0,009	0.030	0.0012	-0.050	0.097	0.0025	-0, 190		
311	005	.0011	009	.022	.0015	062	. 078	. 0041	-0.190 166		
312	003	.0007	.020	.027	.0008	037	. 083	.0015	166 172		
313	.003	.0007	020	.027	.0014	073	. 061	.0038	171		
314	.015	.0011	. 003	. 033	.0015	043	. 097	.0046	171 167		
315	035	.0018	. 107	007	.0010	. 063	. 046	.0006	052		
316	.015	.0014	.003	. 037	.0017	046	. 091	.0031	152		
317	019	. 0019	.088	.009	.0013	.040	. 054	.0010	058		
318								. 0010	. 000		
320	.003	.0015	010	. 033	.0015	059	. 075	.0033	151		
322	.006	.0012	016	. 031	.0016	067	.074	.0041	164		
323	037	. 0021	. 091	017	.0017	. 035	.022	.0027	058		
324	. 004	.0014	008	.029	.0015	060	.076	.0028	161		
325	.019	.0010	.006	. 039	.0013	042	. 099	.0036	164		
326	056	. 0015	. 125	032	.0008	.068	.016	.0007	061		
327	. 042	. 0015	082	. 071	. 0027	142	. 128	. 0058	283		
328	042	. 0015	. 082	021	. 0009	. 029	. 020	.0019	069		
329	038	. 0015	. 107	017	.0008	. 045	. 038	.0021	065		
330	. 056	. 0015	—. 125	. 075	. 0033	178	. 118	.0084	281		

INTERFERENCE OF TAIL SURFACES AND WING AND FUSELAGE

 $\begin{array}{c} \text{TABLE V} \\ \text{PRINCIPAL AERODYNAMIC CHARACTERISTICS OF THE COMBINATIONS} \end{array}$

			Lon-		Angle	Lift-				Aona		Lift	2 (L _{max}
Diagrams representing combinations	Com- bina- tion	Remarks	gitu- dinal posi- tion d/c	verti-	wing set- ting iw	curve slope (per deg.) a A=6.86	Span effi- ciency factor e	$C_{D_{e_{min}}}$	$C_{L_{opt}}$	Aero- dy- namic- center- position n ₀	. 0	$\begin{array}{c} \text{coeffi-}\\ \text{cient}\\ \text{at}\\ \text{inter-}\\ \text{ference}\\ \text{burble}\\ ^1 C_{L_{ib}} \end{array}$	Effective $R = 8.2 \times 10^6$	Effective $R=3.7\times 10^6$
		Tapered N. A. C	A. 00	18-09 a	irfoil wi	th round	l fuselag	е						
		Wing alone				0.077	0.90	0.0093	0.00	0.020	0.000	A1.4	c1.48	°1. 23
	230	(From reference 2.) Tapered fillets. (Plaster finish.)	0	0	0	. 080	3.85	.0117	. 00	. 026	. 000	A1.5	°1. 52	a1. 27
	314	Tapered fillets. Vertical and horizontal tail sursurfaces. $i_s=0^{\circ}$.	0	0	0.	. 086	⁵ . 85	. 0128	6.02	7 100	. 002	A1.7	°1. 73	°1.47
	315	$i_s = -4^{\circ}$; otherwise same as combination 314.	0	0	0	. 087	5. 90	. 0133	6.82	⁷ —. 156	. 102	A1. 6	a1. 62	a1. 34
	316	Tapered fillets. Tail surfaces with end plates. $i_s=0^{\circ}$.	0	0	0	. 086	4. 85	. 0132	6.02	7 098	. 001	A1. 6	a1. 67	a1. 40
	317	$i_s = -4^{\circ}$; otherwise same as combination 316.	0	0	0	. 087	5. 90	. 0134	6.75	7—. 122	. 086	A1. 6	a1, 62	a1. 33
	318	Washed-out fillets. Vertical and horizontal tail surfaces. i_s =0°.	0	0	4	. 086	5. 85	. 0142	633	⁷ —. 129	044	A1. 4	°1.42	a1. 38
	319	Symmetrical tapered fillets	0	0	4	. 080	4. 85	. 0117	. 02	. 027	021	A1. 5	°1. 55	a1. 25
	320	Same as combination 319 but with vertical and horizontal tail surfaces. $i_s=0^{\circ}$.	0	0	4	. 087	5. 85	. 0132	6—. 29	7—. 115	033	A1. 6	°1. 66	a1. 36
	321		0	0	4	. 080	4. 85	. 0120	. 02	. 034	021	A _{1.5}	c1. 50	a1. 22
	322	Vertical and horizontal tail surfaces. $i_3=0^{\circ}$.	0	0	4	. 087	4.85	. 0133	632	7 —. 116	039	A1.6	°1.67	a1.35
	323	$i_s = -4^{\circ}$; otherwise same as combination 322.	0	0	4	.086	3. 85	. 0138	⁶ . 51	⁷ —. 110	. 052	A1. 6	c1. 60	a1. 31
	324	Tail surfaces with end plates. $i_s=0^{\circ}$.	0	0	4	. 086	4. 85	. 0135	6 28	⁷ —. 114	032	A1. 6	c1. 65	a1. 34
	325	Tapered fillets. Horizontal tail surfaces. $i_s=0^{\circ}$.	0	0	0	. 086	4. 85	. 0127	6.06	⁷ —. 087	. 005	A1. 7	¢1.72	a _{1.41}
	306	(From reference 6.) Tapered fillets.	0	. 22	ō	. 080	. 85	. 0122	02	. 032	001	A1. 6	c1. 65	a1. 36
	312	(From reference 6.) Tapered fillets. Horizontal tail surfaces. $i_s=0^{\circ}$.	0	. 22	0	. 087	5. 85	. 0129	6. 14	⁷ —. 133	. 019	A1.8	°1.84	a1. 50
	326	$i_s = -4^{\circ}$; otherwise same as combination 312.	0	. 22	0	. 085	4, 85	. 0137	6.77	7 —. 166	. 116	A1.7	°1.76	a1. 46
	327	$i_s=4^{\circ}$; otherwise same as combination 312.	0	. 22	0	. 086	4. 80	. 0133	61	⁷ —. 125	077	A1.8	°1.81	a1. 50
	308	(From reference 6.) Straight-side junctures.	0	. 22	0	.078	5. 85	. 0118	03	.041	. 010	A1. 5	ь1. 58	a1. 27
	310	(From reference 6.) Straight-side junctures. Horizontal tail surfaces. $i_s=0^{\circ}$.	0	. 22	0	. 086	5. 85	.0128	6. 13	7 —. 127	.016	A1.7	c1.75	a1.46

See footnotes at end of table.

TABLE V—Continued

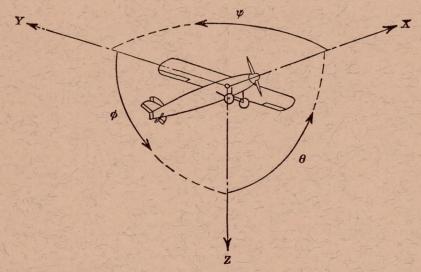
PRINCIPAL AERODYNAMIC CHARACTERISTICS OF THE COMBINATIONS—Continued

			Lon-	Verti-	Angle	Lift-	Span			Aero-		Lift coeffi-	2 C	L_{max}
Diagrams representing combinations	Com- bina- tion	Remarks	gitu- dinal posi- tion d/c	cal posi- tion k/c	wing setting iw	slope (per deg.) a A=6.86		$C_{D_{e_{min}}}$	CLont	$\begin{array}{c} \text{dy-} \\ \text{namic-} \\ \text{center} \\ \text{position} \\ n_0 \end{array}$	C_{m_0}	cient at interference burble CL_{ib} 1	Effective $R=8.2\times 10^6$	Effective $R=3.7\times 10^6$
		Tapered N. A. (C. A	0018-09	airfoil v	vith rour	id fusela	ige						
	307	(From reference 6.) Tapered fillets.	0	22	0	. 081	4. 85	. 0122	. 02	. 030	. 001	^1:5	c1. 57	a1. 26
	313	(From reference 6.) Tapered fillets. Horizontal tail surfaces. i_s =0°.	0	22	0	. 087	5. 85	. 0129	6 15	⁷ —. 127	019	A1. 7	°1.72	a1. 37
	328	$i_s = -4^{\circ}$; otherwise same as combination 313.	0	22	0	. 086	4. 85	. 0133	6. 61	⁷ —. 125	. 077	A1. 6	c1. 66	a1. 30
	187	(From reference 1)	0	22	0	. 079	. 85	. 0124	02	. 039	008	в. 9	c1. 33	a1. 14
	329	Horizontal tail surfaces. $i_* = -4^{\circ}$.	0	22	0	. 085	5. 90	. 0139	6. 69	7—. 137	. 095	В1. 0	c1. 42	a1. 23
	330	$i_s=4^{\circ}$; otherwise same as combination 313.	0	22	0	. 086	5. 80	. 0137	677	⁷ —. 166	115	A1. 6	c1. 74	a1, 38
	309	(From reference 6.) Straight-side junctures.	0	22	0	. 079	4. 85	. 0118	. 03	. 041	010	A1. 5	c1. 50	a1. 23
	311	(From reference 6.) Straight-side junctures. Horizontal tail surfaces. $i_s=0^{\circ}$.	0	22	0	. 086	5. 85	. 0128	6 13	7 125	016	A1. 6	°1. 66	a1.40

¹ Letters refer to types of drag curves associated with the interference burble as follows:



² Letters refer to condition at maximum lift as follows: a reasonably steady at $C_{\bar{\nu}_{max}}$; b small loss of lift beyond $C_{L_{max}}$; and uncertain value of $C_{L_{max}}$.



Positive directions of axes and angles (forces and moments) are shown by arrows

-	Axis	1		Mome	ent abou	it axis	Angle	9	Velocities		
が一門子の	Designation	Sym- bol	Force (parallel to axis) symbol	Designation	Sym- bol	Positive direction	Designa- tion	Sym- bol	Linear (compo- nent along axis)	Angular	
The state of the s	Longitudinal Lateral Normal	X Y Z	X Y Z	Rolling Pitching Yawing	L M N	$\begin{array}{c} Y \longrightarrow Z \\ Z \longrightarrow X \\ X \longrightarrow Y \end{array}$	Roll Pitch Yaw	φ θ ψ	u v w	p q r	

Absolute coefficients of moment

(rolling)

 $C_m = \frac{M}{qcS}$ (pitching)

(yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter

Geometric pitch p,

p/D, V', Pitch ratio

Inflow velocity

Slipstream velocity

Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$ T

Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$ Q,

Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$

Speed-power coefficient = $\sqrt[5]{\frac{\overline{\rho V^5}}{Pn^2}}$ C_s

Efficiency η,

Revolutions per second, r.p.s.

Effective helix angle= $\tan^{-1}\left(\frac{V}{2\pi rn}\right)$ Φ,

5. NUMERICAL RELATIONS

1 hp.=76.04 kg-m/s=550 ft-lb./sec.

1 metric horsepower=1.0132 hp.

1 m.p.h.=0.4470 m.p.s.

1 m.p.s.=2.2369 m.p.h.

1 lb.=0.4536 kg.

1 kg=2.2046 lb.

1 mi.=1,609.35 m=5,280 ft.

1 m=3.2808 ft.

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